

DESCRIPTIVE MINERALOGY OF PUGH QUARRY, NORTHWESTERN OHIO: MARCASITE AND PYRITE¹

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Abstract. Minerals from solution cavities and associated collapse breccias in the Middle Devonian dolostone at Pugh Quarry, Wood County, Ohio were collected and identified. Two types of marcasite were recognized: banded encrustations and euhedral crystals. The banded marcasite is widespread in the mineral zone, especially in the northeastern section of the Quarry, and showed 3 distinct habits: subhedral, globular, and columnar. On freshly exposed surfaces, the colors were greenish gray or a mixture of pale yellow and gray. A characteristic of the banded marcasite is the presence of extensive intergrowth twinning. The euhedral marcasite was found in rocks in all parts of the Quarry, both inside and outside the mineral zone. On freshly broken surfaces, the euhedral crystals were gray-white with a greenish cast. Prismatic and tabular habits were observed. Many of the crystals showed hopper development. Pyrite is not a common mineral in Pugh Quarry. Generally, crystals were small, less than 1 mm in size, greenish brown to yellowish brown in color, and highly lustrous.

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Museums and private mineral collections throughout the U.S. and other countries display crystal specimens of carbonate, sulfate, and sulfide minerals from quarries in the Paleozoic carbonate rocks in the mid-western United States. Occurrence of these minerals has been previously reported (Kraus 1905; Ford and Pogue 1909; Morrison 1935; Howard 1951), but little work has been done on their descriptive mineralogy. It is the purpose of this study to provide a detailed investigation of the mineral assemblages in the carbonate rocks at Pugh Quarry, which is located in the SW $\frac{1}{2}$, SW $\frac{1}{4}$, Sec. 6, T.4N., R.9E. in Milton Township, Wood Co., Ohio. In this report, marcasite and pyrite are described. Methods used for investigation in this study included megascopic identification, microscopic examination of thin sections and polished sections, reflecting goniometric measurement, and x-ray powder diffraction studies.

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MINERAL OCCURRENCE

The stratigraphy at Pugh Quarry is shown in figure 1. Wisconsin age till and lacustrine sands form the overburden at Pugh Quarry. Glacial grooves and striations were exposed on the bedrock around the quarry rim where the overburden had been stripped back. Stylolites occurred in the strata exposed at Pugh Quarry. Petroliferous black shale seams approximately 6 mm thick separated the rocks above and below stylolites, and brecciation was common.

Marcasite, pyrite, and 6 other minerals occurred in rocks at Pugh Quarry (table 1). The minerals were generally restricted to a zone (referred to hereafter as the mineral zone) consisting of nearly continuous bands of cavities about 9 cm thick located in the upper 18 to 24 cm of the Anderson Formation of the Detroit River Group (see fig. 1). Brecciation in this mineral zone locally resembled collapse phenomena associated with areas of cavern development. It was similar to the brecciation described by Jackson and Beales (1967) in ore zones of the Oklahoma-Kansas-Missouri Tri-State Mining District. The breccias in both cases

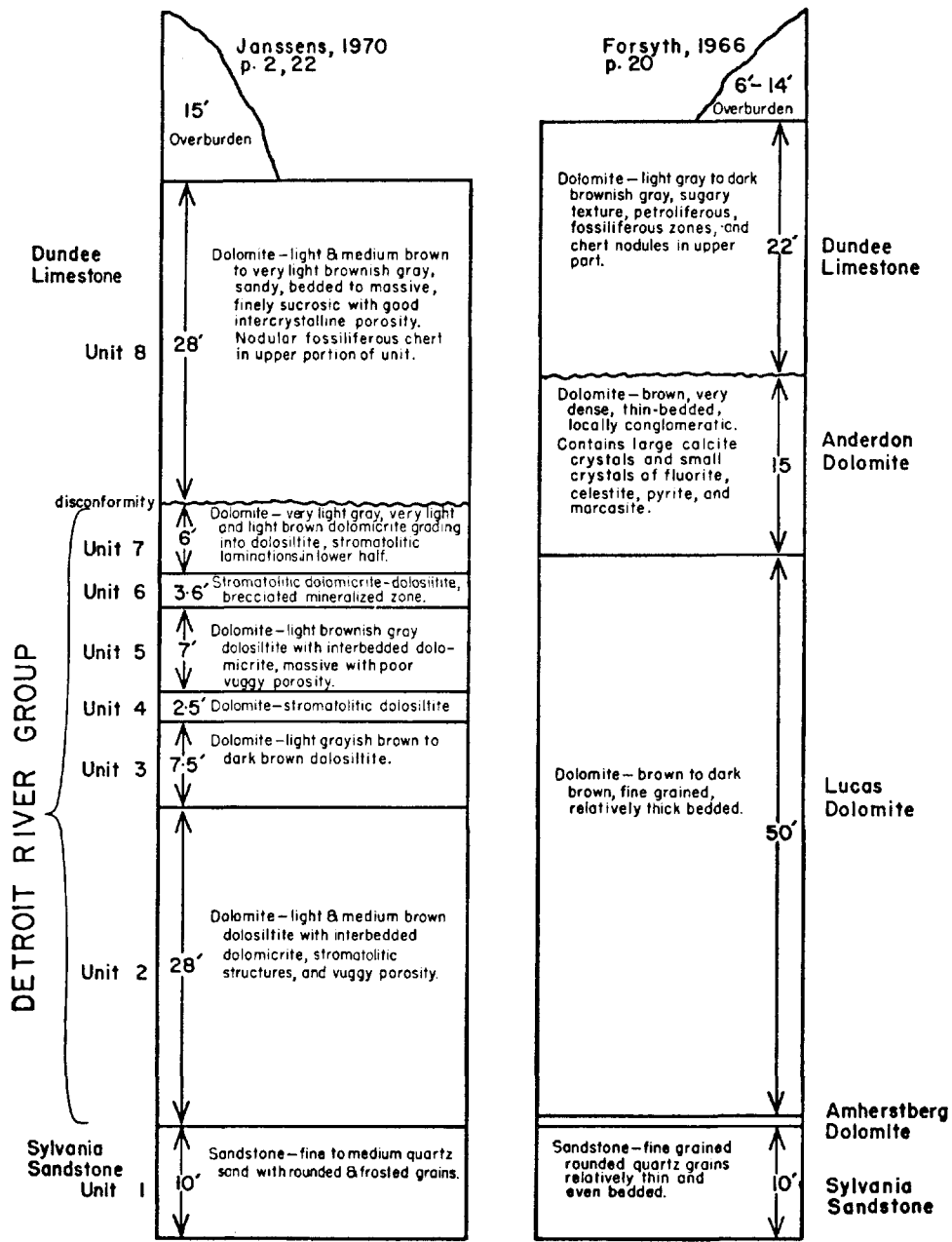


FIGURE 1. Columnar section of rocks exposed at Pugh Quarry after Forsyth (1966) and Janssens (1970).

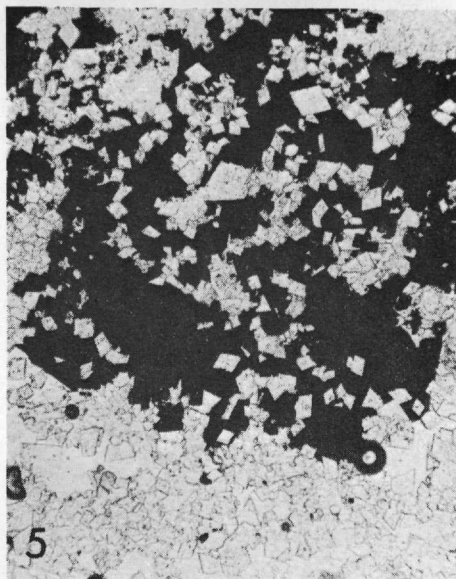
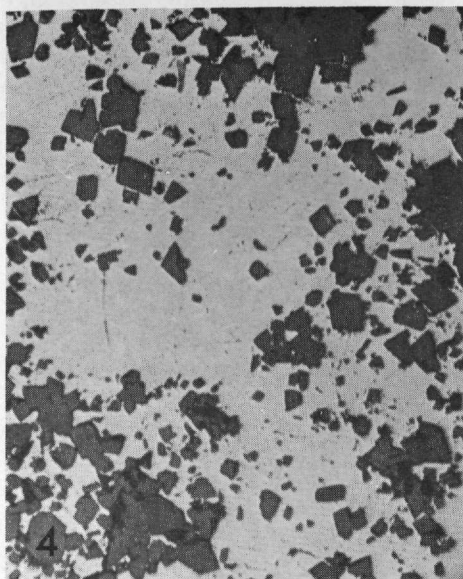
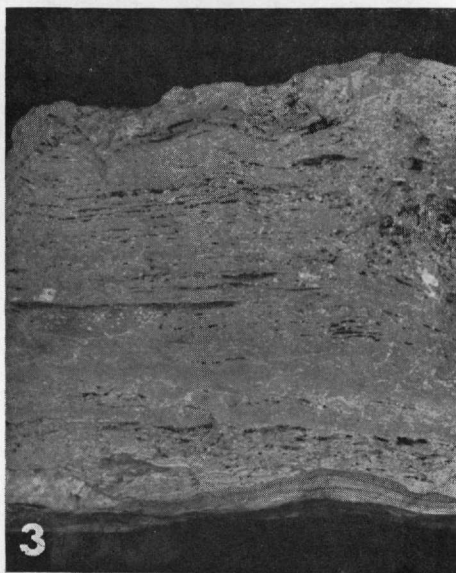
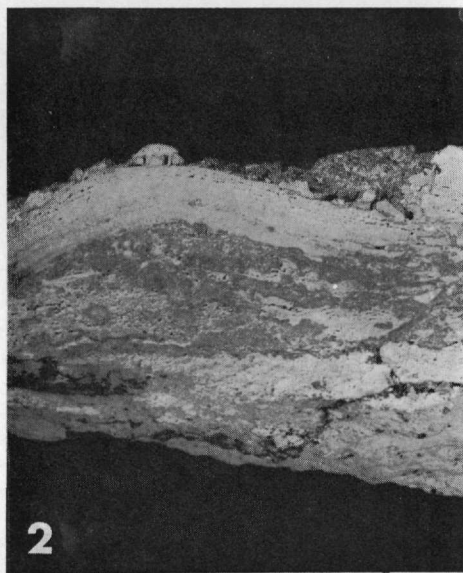


FIGURE 2. Bio-laminar dolostone. The highly porous character of the rock and the wavy laminations are interpreted as stromatolitic in origin. $\times 0.4$

FIGURE 3. Bio-laminar dolostone. The structure may be the remains of a coral organism. Note the areas of marcasite replacement. Actual size.

FIGURE 4. Polished section, one nicol, marcasite (light) and dolomite (dark). Sharp rhombs of dolomite are enclosed in the pore space filling marcasite. $\times 74$

FIGURE 5. Thin section, one nicol, marcasite (dark) and dolomite (light). Sharp rhombs of dolomite are enclosed in pore space filling marcasite. $\times 60$

were cemented by accessory minerals. The specimens used in this study were deposited in the Department of Geology, Miami University, Oxford, Ohio.

TABLE 1
Minerals Identified from Pugh Quarry, Listed by Chemical Group

| Chemical Group | Minerals |
|----------------|-----------------------------------|
| Sulfides | Marcasite Pyrite Sphalerite |
| Carbonates | Calcite Dolomite |
| Halide | Fluorite |
| Sulfates | Barite Celestite |

MARCASITE

Marcasite was a common mineral in the carbonate rocks at Pugh Quarry. Two types were recognized: euhedral crystals and banded encrustations. In this study the term euhedral was used for any crystal which was bounded by crystal surfaces except, perhaps, for the point of attachment to the carbonate rock. Marcasite consisting of solid coatings of intergrown aggregates of radiating or columnar crystals was considered to be banded marcasite.

BANDED MARCASITE

Banded marcasite was widespread in the mineral zone, especially in the north-eastern section of the quarry. Single bands as much as 5 mm thick were found in this area, particularly in portions of the mineral zone showing strong brecciation. In places, marcasite served as the cementing agent between clasts in breccias.

Relation to Host Rock: Dolostones on which the banded marcasite occurred were oölite, structureless rocks with uniform sized crystals, or bio-laminar (Bio-laminar is a general term for those whose structures represent algal stromatolites, stromatoproids, or corals). The dolostones were recrystallized; individual crystals were 0.5 mm or less in maximum dimension (fig. 2 and 3).

Polished section and thin section examinations showed that marcasite pore filling was prevalent in all of the rocks where marcasite had a banded habit. Euhedral dolomite crystals were enclosed totally or in part by marcasite. There was no indication that the development of the marcasite in any way interfered with the recrystallization of the dolomite, indicating an antecedent relationship of the dolomite to the marcasite (fig. 4 and 5).

Several specimens had oölite structures associated with thick banded marcasite. The oölite structures were most distinct along the marcasite-dolomite interfaces, which were characterized by marcasite filling of spaces between oölite (fig. 6).

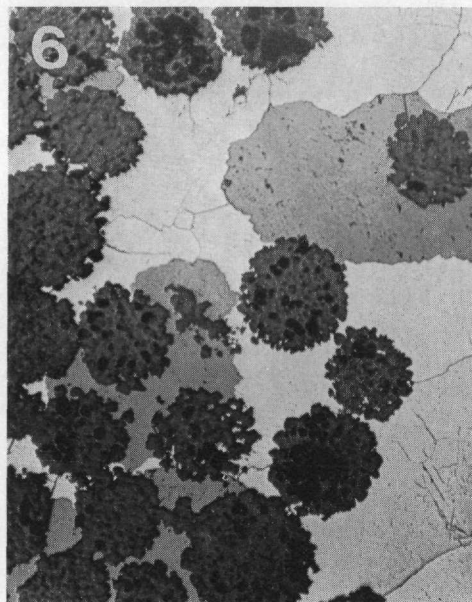


FIGURE 6. Polished section, one nicol, marcasite (white) replacing schalenblende sphalerite (light gray) on recrystallized dolomite oölates (dark gray). $\times 32$

Color: The surface of most banded marcasite from Pugh Quarry was discolored to a reddish brown due to oxidation. Freshly exposed surfaces were greenish gray or a mixture of pale yellow and gray. Irridescent colors, dominantly blues and blue-greens, were characteristic of the natural fracture surfaces of the banded marcasite.

Habit: The banded marcasite showed 3 distinct habits: subhedral, globular, and columnar. The columnar and globular habits were dominant in the very thick massive occurrences of the marcasite bands at Pugh Quarry. The subhedral habit, generally in bands less than 5 mm thick, was made up of elongated individual crystals which were intergrown and formed a solid band of marcasite (fig. 7). The globular habit was characterized by thick encrusting bands of marcasite composed of intergrown crystals which radiated outward from a common center, joining together to form cauliflower-like masses (fig. 8).

The columnar habit, the other main grouping into which a large number of Pugh Quarry banded marcasites were placed, was a habit in which elongated crystals were intergrown in a near-parallel number of produce the columnar appearance. The direction of growth of the columnar crystals was perpendicular to the plane of the band in which they occurred. The band of marcasite formed on a given specimen was generally of even thickness, 5 to 50 mm. Small calcite crystals were seen on the surface of the band, and remnant blebs of schalenblende sphalerite concentrated in horizons were present in the marcasite. Large, though generally rough, crystal terminations were common to the specimens of the columnar banded habit of marcasite.

Several of the marcasite band structures showed crystal terminations on both sides of the band (fig. 9) with opposite sides showing dissimilar crystals. The side of the band toward the open cavities was covered by the large crude crystal terminations and the reverse side was characterized by the presence of small, sharp, nearly euhedral crystals. The interstices between these small crystals were filled with dolostone fragments. Other habits which were observed in marcasite collected from the study area were stalactitic crystal aggregates and stellate twins. These habits were rare (fig. 10).

Crystal Form: Positive identification to forms present as terminations of banded marcasite was not possible for several

reasons. A characteristic of the banded habit of marcasite was the presence of extensive intergrowth twinning. This, combined with the brittle nature of the crystal, made the separation of individual terminated crystal very difficult. Several terminated fragments were separated from the band and mounted on the goniometer. When attempts were made to measure ϕ and ρ angles, it was found that the crystal faces lacked the smoothness and reflectivity necessary to produce an image could be used for measurement. An additional problem encountered in identifying the crystal terminations from the banded marcasite was the degree to which the crystals had been affected by oxidation. Most of the crystal surfaces on the terminations were sufficiently weathered to preclude their use.

The crystal forms present on the terminations of the banded habits of marcasite appeared to be similar to those identified on the crystals of the euhedral habit of marcasite. This was, for the most part, a comparative observation.

Alteration: Virtually all marcasite crystal surfaces showed alteration features when collected. The dominant features were brown coatings and iridescent tarnish films. The brown coating was probably a limonite mineral. A white powder, found in association with marcasite on several specimens after storage for some time in dump places, was examined by x-ray powder diffraction. Results suggested that it was composed of hydrated iron sulfates, rozenite ($\text{FeSO}_4 \cdot 4\text{H}_2\text{O}$) and szomolnokite ($\text{FeSO}_4 \cdot \text{H}_2\text{O}$).

EUHEDRAL MARCASITE

Individual euhedral crystals of marcasite were found in rocks in all parts of the quarry both inside and outside the mineral zone. The Dundee Formation, above the Anderson Formation (fig. 1), contained cavities which resembled external molds of organisms. These openings commonly contained small euhedral marcasite crystals accompanied by small dolomite and fluorite crystals (fig. 11).

Below the mineral zone, marcasite crystals also were found in the algal stromatolitic dolostone of the Lucas Formation. Associated with the eu-

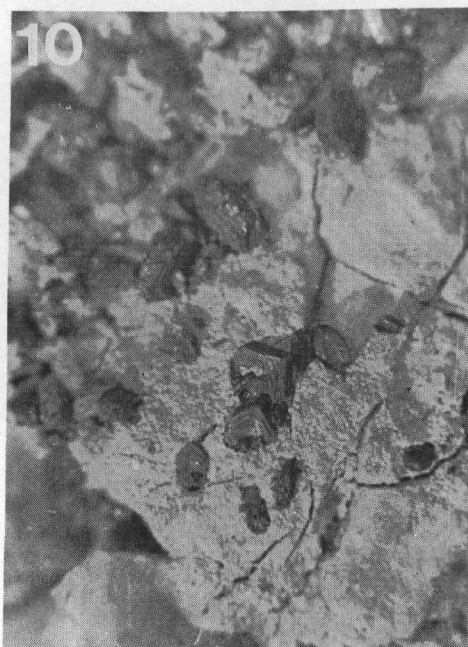
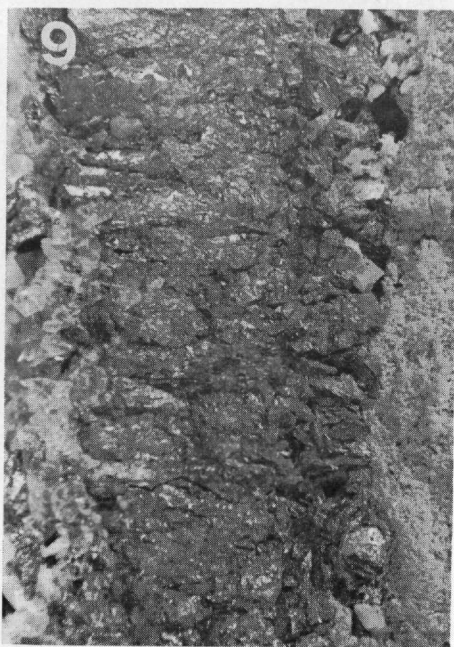
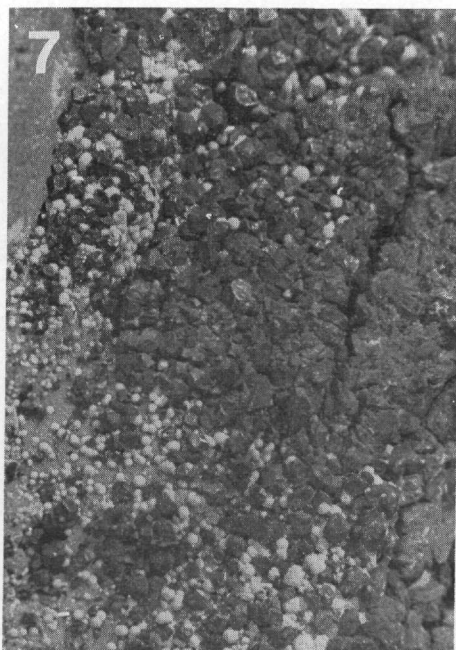


FIGURE 7. Marcasite (dark crystals) and sphalerite (light spherules) on dolostone. The individual marcasite crystals have grown together to form a solid band of marcasite. Note the hemispherical bodies of sphalerite and the isolated euhedral marcasite crystals. $\times 2$

FIGURE 8. Marcasite, globular type, with coating of finely crystalline calcite. Note the cauliflower-like appearance of the marcasite mass. $\times 0.3$

FIGURE 9. Marcasite on dolostone. Note the development of marcasite crystal terminations at the dolostone interface. $\times 3.8$

FIGURE 10. Marcasite, euhedral crystals, on brecciated dolostone. These crystals represent the stellate twinning habit of marcasite. $\times 3$

hedral marcasite crystals were numerous minute crystals of marcasite and sphalerite.

Relation to Host Rock: Two types of interface relationships were recognized between euhedral marcasite crystals and the dolostone host rock. The first type was that crystals occurred as distinct individuals scattered on the walls of cavi-

ties of the host rock. Megascopically, these crystals seemed to be glued to the surface of the dolostone (fig. 12). These crystals were commonly attached to the dolostone along only one crystal face, the remaining faces being free from impingement. Typically, these faces were, as a result, well developed.

In the second type of contact, crystals

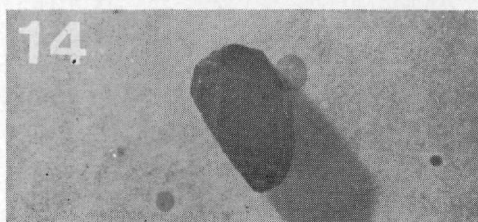
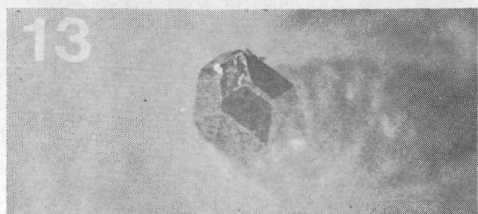
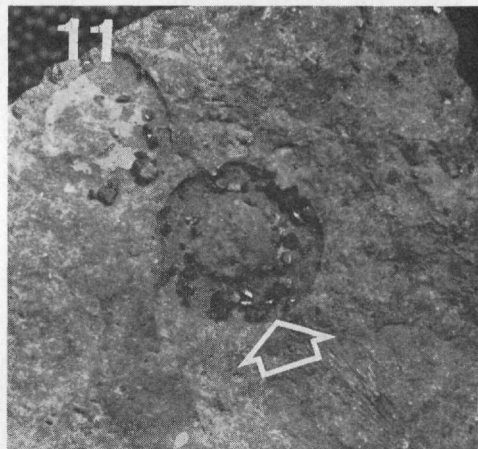


FIGURE 11. External mold of crinoid stem plate, small crystals of marcasite, fluorite, and dolomite are contained in the opening. $\times 2$

FIGURE 12. Euhedral marcasite crystals on dolostone. $\times 3.5$

FIGURE 13. Single euhedral crystal of marcasite showing hopper development on 101 faces. A small reentrant angle marking the location of the twin plane, 101, in the crystal can be seen. The pseudobipyramidal appearance of the crystal is apparent. $\times 10$

FIGURE 14. Euhedral marcasite crystal. The small face commonly associated with twinned euhedral crystals is shown. $\times 10$

FIGURE 15. Euhedral marcasite crystal. The small face commonly associated with twinning on euhedral crystals, hopper development of faces at the center of crystal, and pseudobipyramidal character of the four faces on the end of the crystal can be seen. $\times 10$

of marcasite were removed from the dolostone with little difficulty, leaving behind a well formed "external mold" of the crystal faces. The relation between the host rock and the marcasite crystal was similar to that between an internal mold and external mold of an organism after the shell was removed.

Color: Euhedral marcasite was more colorful than banded marcasite. The colors observed on the crystal faces were caused by an oxidation coating. When examined at arm's length, the color of the crystals appeared to be an olive brown in daylight. Upon closer examination, it became apparent that the range of colors covered the entire spectrum, although green was dominant. On freshly broken surfaces, these crystals were grey-white with a greenish cast.

Habit: Euhedral marcasite exhibited prismatic and tabular habits. Many of the crystals showed hopper development (fig. 13). Prismatic crystals were prevalent. Crystals of this habit closely resembled octahedra with small cube modifications, but angular parameters of these showed them to be orthorhombic (fig. 12).

Two generations of marcasite growth, possibly more, were indicated by the presence of hopper crystals. The final stage of growth was notably more rapid than that of the earlier stages. Hopper development on the (010) and (001) faces of marcasite was attributable to the greater energies released by ions attaching to the edges and corners of a crystal than those attaching to the faces (Grigor'ev 1961). Once the process of overgrowth began, it perpetuated itself directionally along the edges of a crystal before growing appreciably in towards the center of the crystal face (fig. 14 and 15). This type of overgrowth indicated a period of rapid crystal development.

Variation in the dimensions of the banded marcasite was found to be great. This was not found to be the case with the euhedral marcasite, with 4 mm being the maximum dimension for any euhedral crystal. No minimum dimension was established; however, it was noted that most of these crystals fell within the 1 to 3 mm range.

Crystal Form: Euhedral crystals were examined with a binocular microscope (20X), and 5 well developed crystals were selected for measurements of ϕ and ρ values between their crystal forms. For {101} ϕ had a constant value of 90° (90° , Palache *et al* 1944, p. 313) and ρ varied from 52° to $52^\circ 45'$ ($52^\circ 41'$). For {110} ϕ varied from 47° to 51° ($50^\circ 40'$) and ρ had a constant value of 90° (90°). For {011} ϕ was 0° (0°) and ρ varied from $32^\circ 30'$ to 34° ($31^\circ 59'$). For {010} ϕ was 0° (0°) and ρ was 90° (90°).

Twinning on {101} was present in nearly all of the euhedral crystals and was readily apparent in polished sections. A {011} twin plane had also been reported for marcasite (Palache *et al* 1944), but no evidence for this type of twinning was found in the Pugh Quarry specimens examined.

On many of the crystals {101} faces predominated and characteristically showed the hopper growth discussed above. Step growth and pitting were also present on faces of this form, but vicinal faces did not tend to develop. There was commonly unequal development of the different faces of this form. The development of the (101) was similar to that of the $(\bar{1}0\bar{1})$, and $(\bar{1}01)$ developed similar to $(10\bar{1})$. Commonly the (101)- $(\bar{1}0\bar{1})$ face pair was significantly larger than the $(\bar{1}01)$ - $(10\bar{1})$ face pair. The twin plane generally bisected the crystals, and the associated re-entrant angles comprised the $(\bar{1}01)$ and $(10\bar{1})$ faces.

On the basis of their different ϕ and ρ values, {011} prisms were distinguishable from {110} prisms. Striations parallel with the [100] axes and the presence of red-brown to yellow-brown oxidation coating were common to {011} prisms. All faces of this form tended to be developed equally. Both the prominent striations and the red-brown, yellow-brown oxidation coating of the {011} prisms were lacking on {110} prisms. Vicinal faces, step growth, and triangular growth pits were found on the {110} prism faces of many crystals. Positive and negative faces of {110} prisms were developed equally.

The only pinacoid found on the crystals examined was {010}. Characteristically,

the $\{010\}$ faces were among the larger faces developed on these crystals. Parallel growth, vicinal face development, and the presence of numerous high order $\{hk0\}$ prisms all contributed to curved surfaces and the generally distorted nature of this form. On many crystals the $\{010\}$ surfaces were so poor that no reliable angular measurements could be made utilizing this form.

The combination of the 4 forms, $\{101\}$ twinning, and the nature of development of the various forms all contributed to crystals with habits which were deceptively simple in appearance. Faces of the $\{011\}$ and $\{110\}$ prisms were commonly of equal area. In many cases the twinning had resulted in a situation where all 4 faces of one prism form occurred on the same end of the crystal. The appearance of this was exactly that of a bipyramid, distinguishable only on the basis of ϕ and ρ measurements. Even when the prism faces were correctly positioned, the resemblance between the $\{110\}$ and $\{011\}$ forms was so close that the 4 faces collectively resembled a bipyramidal form (figs. 12, 13, and 15). No true pyramid faces were observed on any of the euhedral crystals. Faces of one or both of the bipyramidal forms ($\{111\}$ or $\{122\}$) may have been present on the terminations of the banded marcasite discussed earlier, but it was not possible to identify them positively. The dominant forms which control led the habits observed on the Pugh Quarry marcasite were the $\{010\}$ pinacoid and $\{101\}$ prism.

PYRITE

Pyrite was not a common mineral in Pugh Quarry. Generally, crystals were small, less than 1 mm in size, greenish brown to yellowish brown in color, and highly lustrous. The octahedron, $\{111\}$, was the predominant form. The apices of the octahedra were truncated by small pyritohedra, $\{102\}$ (fig. 16), which showed characteristic twinning striations. The $\{011\}$ form was also present on some of the crystals. Suggestions of the cube, $\{100\}$, were observed but positive identification of this form could not be made.

A curious growth feature observed on most of the pyrite crystals consisted of

reentrant angles occurring at the intersection line of the octahedral crystal faces. These angles did not coincide with the twin laws of pyrite and were interpreted here as growth features, possibly representing a second generation of pyrite. The central portions of all octahedral crystal faces were pitted. The bounding faces of these pits consisted of pyritohedral surfaces.

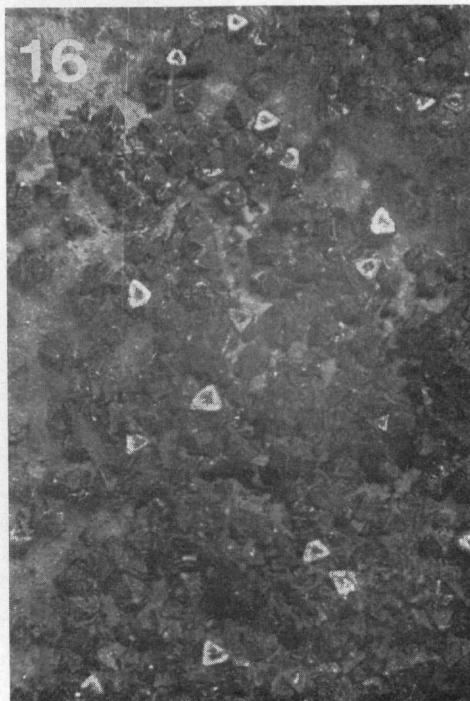


FIGURE 16. Pyrite on dolostone. Octahedral and pyritohedral crystal forms are visible. $\times 5$

The characteristic used to distinguish pyrite from marcasite in polished section examination was its anomalous anisotropism under cross nicols (Ramdohr 1969). Marcasite, and particularly Pugh Quarry marcasite, exhibits extremely strong anisotropism accompanied by vivid interference colors. In plane polarized lights pyrite is pale yellow to creamy yellow, whereas marcasite is nearly white. The reflectivities of the 2 minerals are essentially identical.

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